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(54) Data encoded optical pulse generator

(57) The apparatus and method according to the present invention includes a semiconductor laser-modulator which is used to simultaneously generate optical pulses and encode data. The optical data output from the laser-modulator are soliton pulses in RZ format suitable for transmission in long distance optical communications.

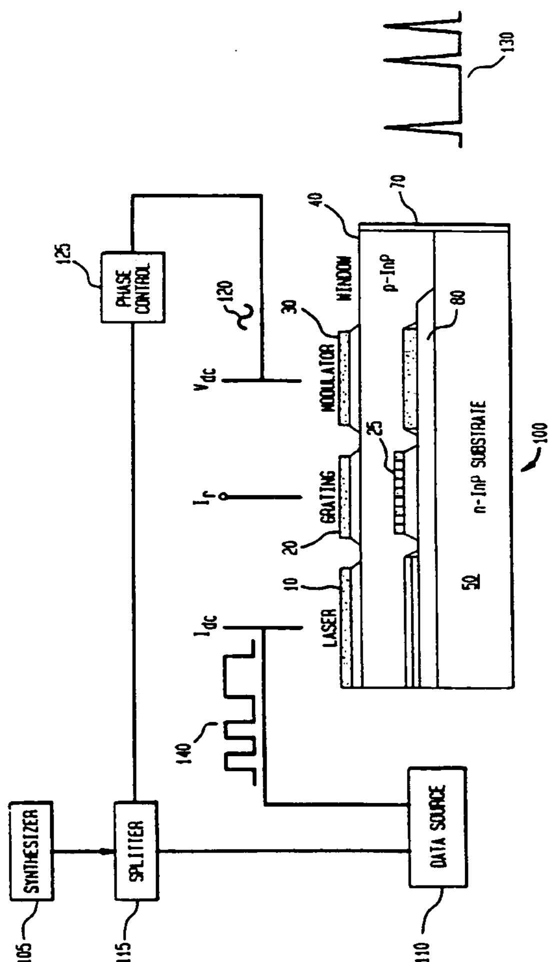

FIG. 1

CORRIGENDUM issued on 14.02.96

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Description

Background of the Invention

TECHNICAL FIELD

This invention relates generally to an optical pulse generator and more particularly to a data encoded optical pulse generator for generating soliton pulses.

DISCUSSION OF RELATED ART

A useful measure of the performance characteristics of a digital optical data communication system is the well-known "rate-length product", i.e., the product of the system data rate and the length of transmission. It is often a design goal to achieve the highest data rate through the longest repeaterless length and consequently the highest rate-length product.

Components used in long distance optical data communication systems for producing a high rate-length product typically include: a light source such as a laser diode; a high speed modulator which modulates the light source at the system bit rate, usually by amplitude modulating the light produced by the laser; a low loss, low dispersion fiber medium; a photodetector such as a pi-n photodiode or an avalanche photodiode having a high speed response for detecting the transmitted optical signals; and a receiver coupled to the photodetector for amplifying and decoding the received optical signals. Components such as optical amplifiers and repeaters can further extend the transmission length and increase the rate-length product.

The system rate-length product is a function of the transmission format as well as of the hardware components used. In current optical communication systems, data is transmitted in non-return-to-zero (NRZ) format, with ones and zeros represented by the presence or absence of light in a given time slot. This format is typically implemented by using a laser to generate a CW light beam, then modulating the light beam with an electro-optic modulator. The modulator may be a separate semiconductor device. Recently, the laser and modulator have been fabricated on a single chip, resulting in an integrated transmitter for NRZ communications systems.

The rate-length product attainable with the NRZ transmission format is ultimately limited by dispersion in the optical fiber. To reach very high data rates, communications links employing soliton pulses have been proposed. Solitons are optical pulses which take advantage of the nonlinearity of the fiber to maintain pulse shape during transmission. Soliton pulses can be transmitter over long lengths of fiber at rates of 10 Gb/s and higher. The soliton pulse width is less than the width of the time slot and is thus transmitted in return to zero (RZ) format; i.e., the amplitude of the light returns to zero during each time slot. An RZ format is also desirable for systems employing optical time-division-multiplexing and demultiplexing.

Despite recent advances in the development of optical transmitters, a need exists for a transmitter which produces soliton pulses and is wavelength tunable, compact, manufacturable and relatively inexpensive to operate for producing RZ encoded data. One approach is to use a gain-switched laser to generate pulses, then encode data onto the pulses with a modulator. However, gainswitching produces chirp, which causes significant penalties in transmission due to fiber dispersion, and may also degrade the performance of a soliton system. Another approach is to use a mode-locked laser to generate pulses and again encode data with a modulator. However, monolithic mode-locked lasers operate only at fixed frequencies which are determined by their cavity length. The fabrication of devices with a desired operating frequency may be difficult, especially if the laser is to be integrated with the modulator for data encoding. External-cavity mode-locked lasers offer more flexibility in operation frequency, but are bulky and sensitive to the environment, making them unsuitable for practical applications.

Integrated laser-modulators previously suitable for NRZ data transmitters can be operated as transmitters for producing soliton pulses. In such case the laser is operated CW and the modulator is driven with an RF sinusoid, resulting in a time-varying transmission which converts the CW laser light to pulses. This type of pulse source is simple, compact, frequency and wavelength tunable, and possesses spectral characteristics suitable for long distance transmissions. A soliton transmitter based on this pulse source, consisting of a laser integrated with two modulators, has been demonstrated. In this approach, the first modulator is used to convert CW laser light to pulses and the second modulator is used to encode data. While this technique is attractive, the integration of a laser and two modulators requiring two high-speed contacts is difficult. A simpler device would be preferable.

SUMMARY OF THE INVENTION

Briefly, according to the present invention, an optical pulse generator, preferably an integrated semiconductor laser-modulator is used to simultaneously generate pulses and encode data in RZ format, eliminating the need for an external modulator and reducing cost, bulk and complexity. The laser is preferably of the Distributed Bragg Reflector (DBR) type and the laser-modulator is variable in pulse width, repetition rate and wavelength.

In a preferred embodiment, the apparatus according to the present invention comprises: a semiconductor laser and a semiconductor modulator, the laser for providing an optical signal source, the modulator for modulating the optical signal source: means for biasing the laser with a constant current and electrical data pulses to the laser to produce optical data pulses; and means for biasing the modulator with a constant voltage and applying

a periodic analog, electrical signal, for example, a sinusoid to the modulator to further modulate the optical data pulses from the laser for outputting the encoded optical pulses.

The electrical data pulses applied to the laser may be in non-return-to-zero format. The bit rate of the data pulses and the analog signal applied to the modulator may be selectively variable in repetition rate. The encoded optical data output from the semiconductor laser-modulator are in return-to-zero format. The semiconductor laser-modulator further includes means for selectively varying the wavelength of the encoded optical pulses. Preferably, the means for varying the output wavelength is by use of a surface layer resistor which may be heated for selectively varying the temperature within the semiconductor laser.

According to another embodiment of the present invention, the apparatus comprises: a semiconductor laser and a modulator, the laser for providing an optical source, the modulator for modulating the optical source; means for biasing the laser sufficient to produce a CW optical output; means for applying electrical data pulses to the modulator to modulate the CW optical output to produce optical data pulses corresponding to the electrical data pulses.

The electrical data pulses applied to the modulator are in return-to-zero format and the optical data pulses output from the laser-modulator are also in return-to-zero format. The means for applying electrical data pulses to the modulator section includes a device for performing a gating operation of an NRZ data input with a periodic analog signal input to provide electrical RZ data pulses.

The present invention is also directed to a method for generating soliton pulses from a semiconductor device having a laser and a modulator, comprising the steps of: biasing the laser with a constant current at near lasing threshold; applying electrical data pulses at a selected bit rate to the laser for producing optical data pulses; reverse biasing the modulator by a constant voltage source; and applying to the modulator a sinusoidal source having a frequency corresponding to said bit rate.

According to another method of the invention for generating soliton pulses from a semiconductor laser and a modulator, the laser is biased for producing a CW laser output, and an electrical RZ data signal is applied to the modulator for transmitting said laser output when an electrical one is present for generating RZ optical data pulses corresponding to said RZ data signal.

BRIEF DESCRIPTION OF THE DRAWINGS

The features and advantages of the invention may be better understood from the following detailed description when read in conjunction with the following drawings:

Figure 1 is a schematic of the apparatus according to a preferred embodiment of the present invention;

Figure 2 shows the absorption characteristics of the modulator as a graph of voltage bias versus extinction ratio;

Figure 3 shows a graph of the pulse width characteristics versus frequency of the modulator;

Figure 4A shows an eye pattern of the optical pulse output of the semiconductor laser/modulator device and

Figure 4B shows the spectral waveshape of the optical outputs with and without digital encoding;

Figure 5 is a schematic of the apparatus according to a second preferred embodiment of the present invention;

Figure 6 shows an eye pattern of the optical pulse output of the semiconductor device according to the second preferred embodiment of the present invention;

Figure 7A shows a representative pulse of the optical output and Figure 7B shows the corresponding spectrum; and

Figure 8 is a schematic of the apparatus according to an alternative biasing arrangement to the embodiment as shown in Figure 5.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to Figure 1, which shows a view of a data encoded optical pulse generator according to a preferred embodiment of the present invention. A semiconductor device 100 preferably includes a bulk electroabsorption modulator and a multiple quantum well Distributed Bragg Reflector (DBR) laser. The device 100 may be fabricated conventionally, and it is apparent to one ordinarily skilled in the art that the techniques of the present invention for generating data encoded optical pulses are also applicable to pulse generators having a semiconductor laser and an external modulator.

The DBR laser 10 is preferably operated to output pulses at around 1557 um wavelength but is. discretely tunable over discrete wavelengths from around 1557um to 1563um. Laser wavelength tuning can be by carrier injection or by surface layer resistive heating. Both techniques employ the known principle that the wavelength of a semiconductor laser will change with temperature since its refractive index varies with temperature. The tuning capability of the DBR laser according to the present invention is preferably by surface layer resistive heating of a 220 ohm resistor 20 made on the top metalization layer over the grating region 25. Current IR is selectively applied to resistor 20 for selectively varying

the temperature of the device and tune the optical output wavelength.

According to a preferred embodiment of the present invention the laser/modulator 100 is biased to output encoded optical data pulses in RZ format 130.

As shown in Figure 1, data pulses are generated by biasing the laser section 10 at near lasing threshold with a constant current Idc and applying digital data from data source 110. The digital data is preferably in NRZ format. The output of the laser 10 is an optical signal corresponding to the electrical signal 140. The modulator 30 is then biased with a constant voltage source Vdc and an analog signal 120 is also applied. The modulator 30 further modulates the laser output. The resultant pulses 130 output from the laser/modulator 100 are in RZ format as shown. The analog signal 120 and the clock for the data source 110 originate from synthesizer 105, which is a high speed oscillator. For illustration, the synthesizer 105 operates at around 2.5 Ghz for the present preferred embodiment. The output of the synthesizer 105 is split by splitter 115 for providing the clock input to the data source 110 and to a phase control 125 for varying the phase of the analog signal 120.

Figure 2 shows the measured absorption characteristic for the modulator 30. For example, the DC extinction is 25dB for a reverse bias of -4.5V. By biasing the modulator near full extinction and applying a sinusoidal voltage which temporarily reduces the attenuation, the modulator generates picosecond pulses in a range limited only by its frequency response.

For illustrative purposes, the laser 10 is biased with a constant current of 65mA and the modulator is biased as described above. Figure 3 is a plot of the observed pulse width of the pulses output from the semiconductor device 100 at frequencies from 1 to 12 Ghz. At 10 Ghz, for example, the DC bias Vdc applied to the modulator 30 is -2.25V and the RF power of the sinusoidal signal 120 is 27dBm as measured into 50 ohms. The resultant pulse width is 25 ps with an on/off ratio of 17dB and the spectral width is approximately 16 Ghz. The corresponding time-bandwidth product is 0.40.

According to the first preferred embodiment of the present invention, the laser 10 is biased near threshold with Idc at 30mA and is also directly encoded with digital data from data source 110. The data is applied to the laser contact with a peak to peak voltage of about 0.7 volts at, for example, 2.5 gigabits per second. The phase of the sinusoidal drive to the modulator 30 is optimized to align the bit period to the peak amplitude of the sine wave. Fig 4A shows the RZ eye pattern observed on a sampling oscilloscope of a pseudo random data pulse train applied to laser 10. The laser chirp is minimized and narrow spectral characteristics are achieved by maintaining a relatively small modulation signal. The peak wavelength excursions are 0.4 angstrom.

Figure 4B shows the optical spectra of the two cases for pulses (a) with encoded data applied to the laser and (b) without encoded data applied to the laser.

As shown, there is approximately 25% broadening of the spectral width for the digitally encoded case (a). The estimated time bandwidth product broadens from 0.356 to 0.481.

According to a second preferred embodiment, the laser-modulator device 100 produces optical RZ data with another biasing technique. Referring to Fig. 5, the laser 10 is biased at 60 mA to output a CW laser beam, which is then modulated by the modulator 30, which is in turn driven by a digital data signal 570 in RZ format, producing an optical RZ data 580 at the output of the laser-modulator device 100. The components used for producing the digital data signal 570 includes a dual-gate FET 500 for gating an NRZ data stream with an analog signal to produce an RZ format signal corresponding to the NRZ data. The gating process is similar to a logical "AND" operation. The dual gate FET may be any conventional dual gate field effect transistor capable of operating at high frequencies such as up to around 15 Ghz. It is apparent to one skilled in the art that any other transistor(s) configured as shown in Figure 5 can accomplish the same function. The NRZ datastream input to the FET 500 is produced from pattern generator 540, a high speed data source which produces a preset data pattern in NRZ format at a bit rate corresponding to the rate of the clock input. The sinusoidal signal 535, in this case a 2.5 Ghz sinusoidal signal, is output from phase control 130. The 2.5 Ghz sinusoid and the clock for the pattern generator 540 originate from synthesizer 510, which is a 2.5 Ghz oscillator, the output of which is split by splitter 520. One of the outputs of the splitter is used as the clock input to the pattern generator 540 and the other splitter output is input to the phase control 530, which may be a variable delay line, or any equivalent, for adjusting the phase of the 2.5 Ghz sinusoid signal to coincide with the corresponding bit pattern period of the signal output from pattern generator 540. The dual gate FET 500 performs an AND operation of the NRZ data and the 2.5 Ghz sinusoidal inputs to produce an electrical data stream which is the same data input from the data generator but converted to an RZ format. The output of the FET is further amplified by amplifier 550 before it is used to drive the modulator 30 of the laser-modulator device 100.

As configured, the CW laser output of laser 10 is modulated by modulator 30 so that optical pulses are output when an electrical "one" is present to produce RZ optical pulses 580.

Figure 6 shows an eye pattern of the optical pulses output from the apparatus according to the second preferred embodiment of the present invention.

Figure 7A and Figure 7B show a representative output waveform and the corresponding spectrum, respectively.

Due to the non linear switching characteristics of the modulator, the optical output pulses are narrower than the input electrical pulses. The pulse width is 85 ps and could be further reduced by adding higher order harmonics to the electrical pulse shaping input. There is little or

no chirp added by data encoding with the modulator.

Figure 8 shows a technique for adding higher order harmonics to the electrical pulse shaping circuit. This technique produces an analog signal by superimposing sinusoidal signals which are harmonics of the oscillation signal originating from the synthesizer 510. The splitter 520 is a three way splitter (which may comprise two two-way splitters), with one output being the clock signal for the pattern generator 540, the second output being a first sinusoid signal and the third output being input to a frequency doubler 555 for creating the second harmonic of the first sinusoid. The output from the frequency doubler 575 may be phase adjusted by another phase controller 565 before being combined with the first sinusoid signal by combiner 585. The output of the combiner 585 is a superimposed, periodic analog signal 535 for inputting to the FET 500. It is readily apparent to one ordinary skilled in the art that a comb generator may be used in place of the frequency doubler arrangement to generate a short electrical pulse for shaping the electrical data.

The above description is illustrative of the application of the principles of the present invention. Modifications and other arrangements of the invention can be made by those skilled in the art without departing from the scope of the invention.

Claims

1. An apparatus for producing encoded optical pulses for use in an optical communication system, such apparatus comprising:

   a semiconductor laser for providing an optical signal source;

   a modulator for modulating said optical signal source;

   means for biasing said laser with a constant current and applying electrical data pulses to said laser to produce optical data pulses; and

   means for biasing said modulator with a constant voltage and applying a periodic analog electrical signal to said modulator section to further modulate said optical data pulses for outputting in RZ format said encoded optical pulses.

2. The apparatus according to claim 1 wherein said electrical data pulses are in non-return-to-zero format.

3. The apparatus according to claim 1 wherein said means for applying said analog electrical signal includes means for selectively varying the repetition rate of said analog signal.

4. The apparatus according to claim 1 wherein said means for applying said analog electrical signal includes means for superimposing harmonically related sinusoidal signals to produce said analog electrical signal.

5. The apparatus-according to claim 1 wherein said semiconductor laser outputs said optical pulses at a selected wavelength and said semiconductor laser further includes means for varying said wavelength.

6. The apparatus according to claim 5 wherein said means for varying said wavelength includes a surface layer resistor for selectively varying the temperature within said semiconductor laser.

7. The apparatus according to claim 1 wherein said semiconductor laser is integrated with said modulator in one semiconductor device.

8. An apparatus for producing encoded optical pulses for transmission in an optical communication system, comprising:

   a semiconductor a laser and a modulator, the laser for providing an optical source, the modulator for modulating the optical source;

   means for biasing said laser output sufficient to produce a CW optical output;

   means for applying RZ electrical data pulses to said modulator to modulate said CW optical output to produce RZ optical data pulses corresponding to said RZ electrical data pulses.

9. The apparatus according to claim 8 wherein said means for applying electrical data pulses to said modulator includes a device for performing a gating operation of an NRZ data input with a periodic analog signal input to provide electrical RZ data pulses.

10. The apparatus according to claim 8 wherein said means for applying RZ electrical data pulses includes means for superimposing harmonically related sinusoidal signals for producing periodic analog signal for combining with an NRZ input to provide said RZ electrical data pulses.

FIG. 1

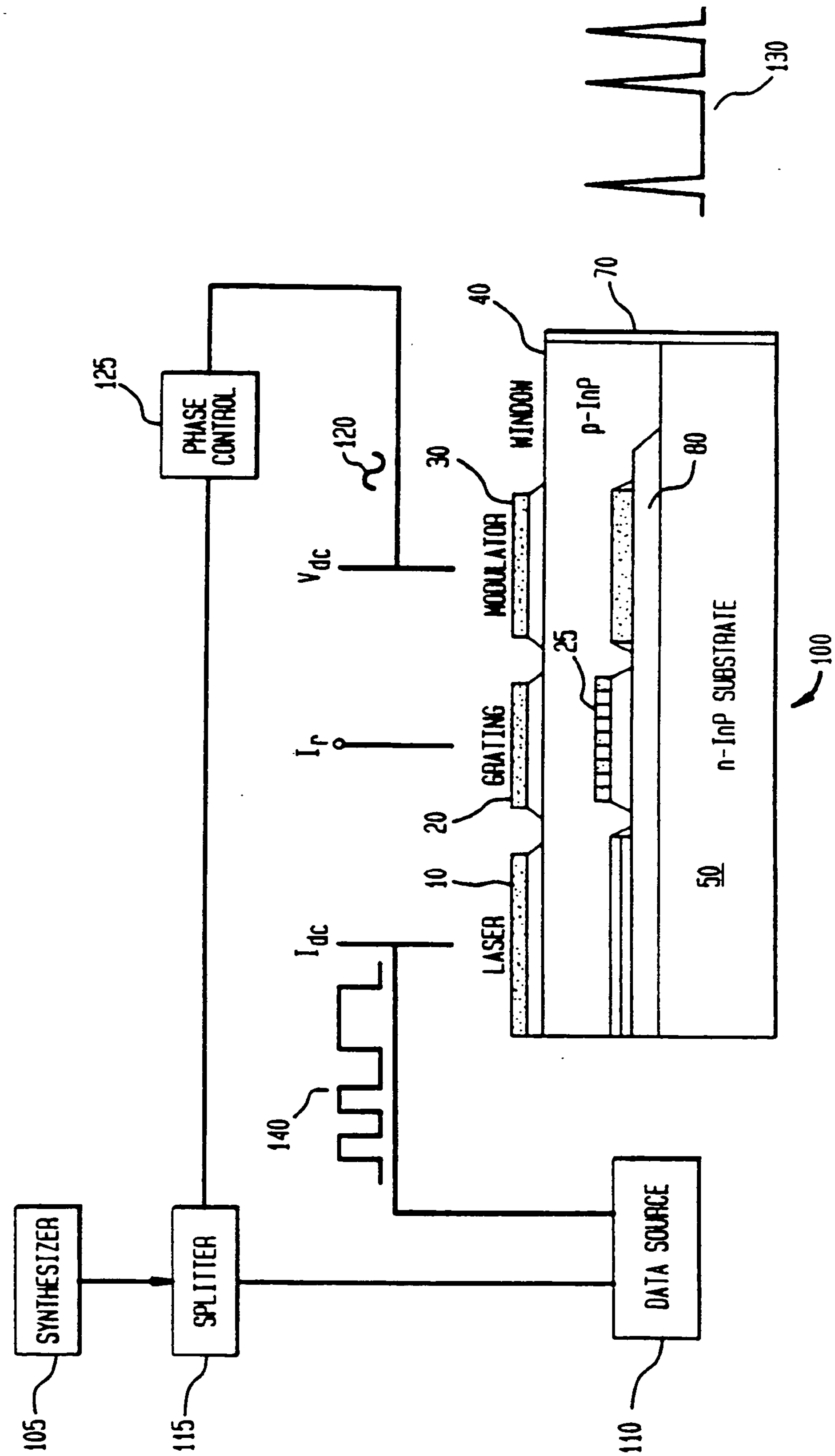

SYNTHESIZER
SPLITTER
DATA SOURCE
PHASE CONTROL
105
115
110
125
120
130
140
100
I_{dc}
I_r
V_{dc}
LASER
GRATING
MODULATOR
WINDOW
10
20
25
30
40
70
80
p-InP
n-InP SUBSTRATE
50

FIG. 2

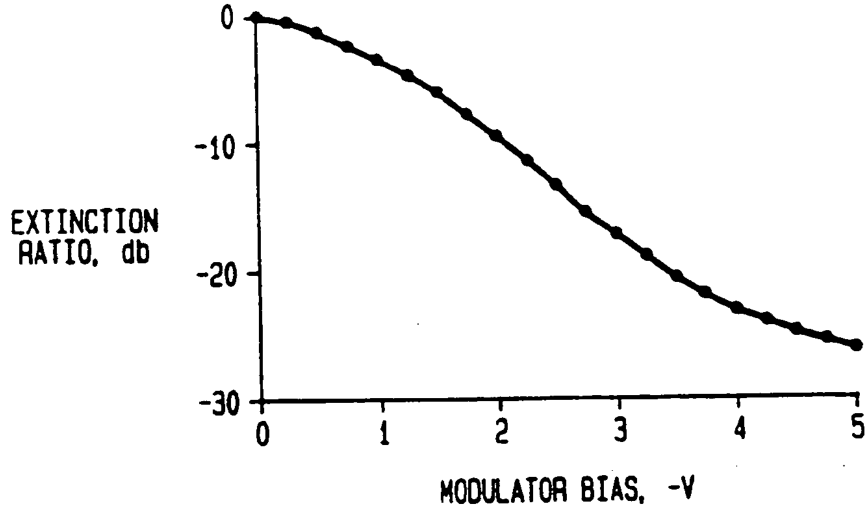

0
-10
-20
-30
EXTINCTION RATIO, db
0
1
2
3
4
5
MODULATOR BIAS, -V

FIG. 3

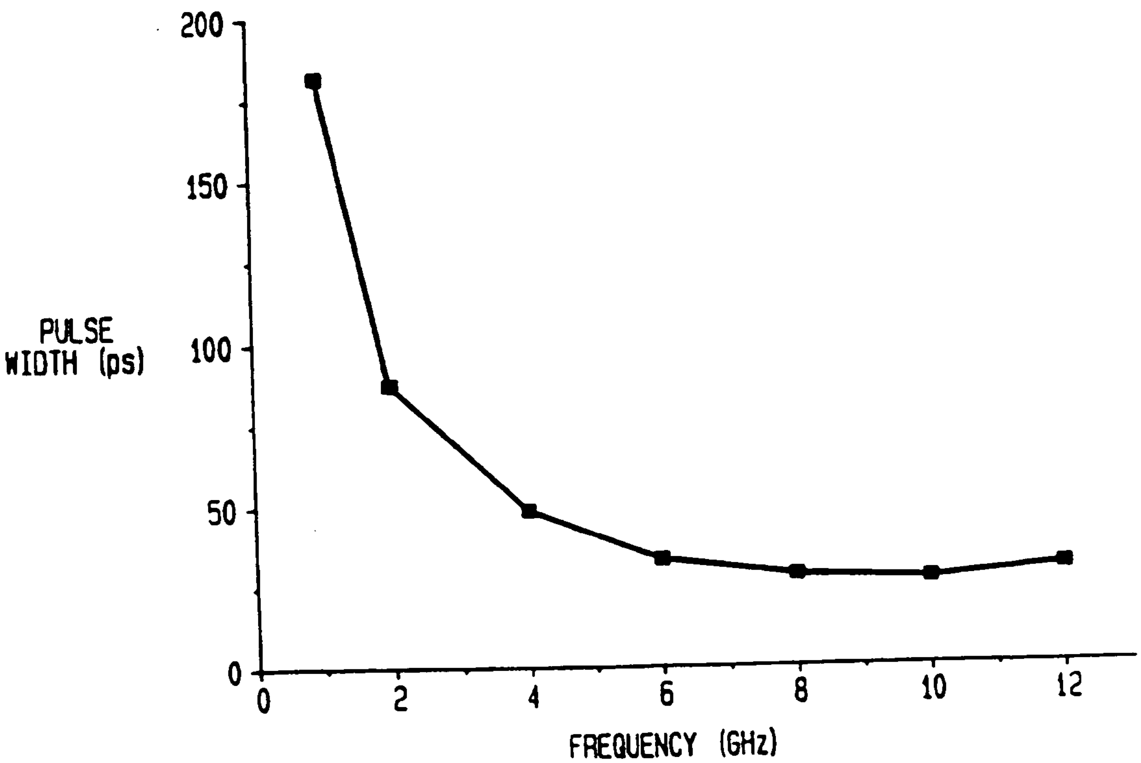

200
150
100
50
0
PULSE WIDTH (ps)
0
2
4
6
8
10
12
FREQUENCY (GHz)

FIG. 4A

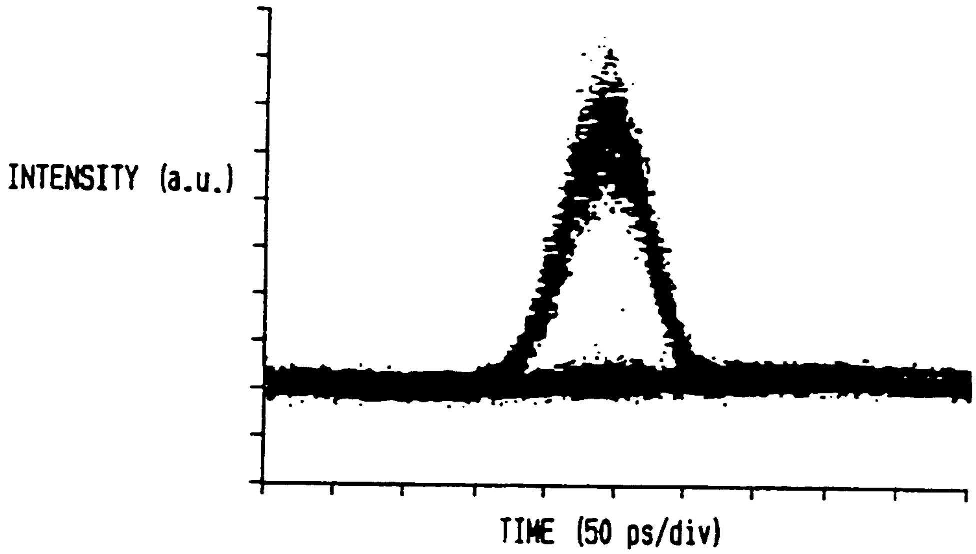

INTENSITY (a.u.)
TIME (50 ps/div)

FIG. 4B

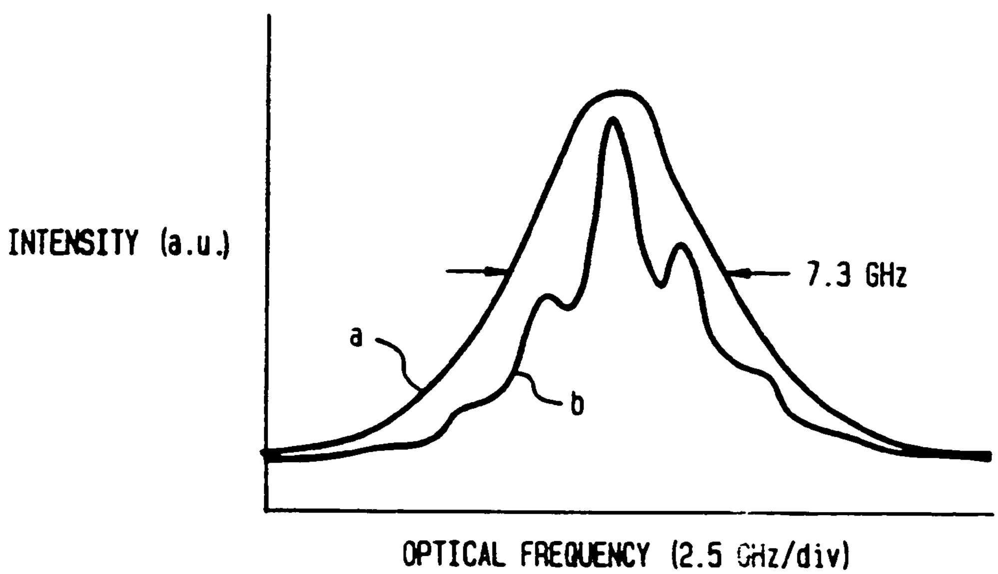

INTENSITY (a.u.)
7.3 GHz
a
b
OPTICAL FREQUENCY (2.5 GHz/div)

FIG. 5

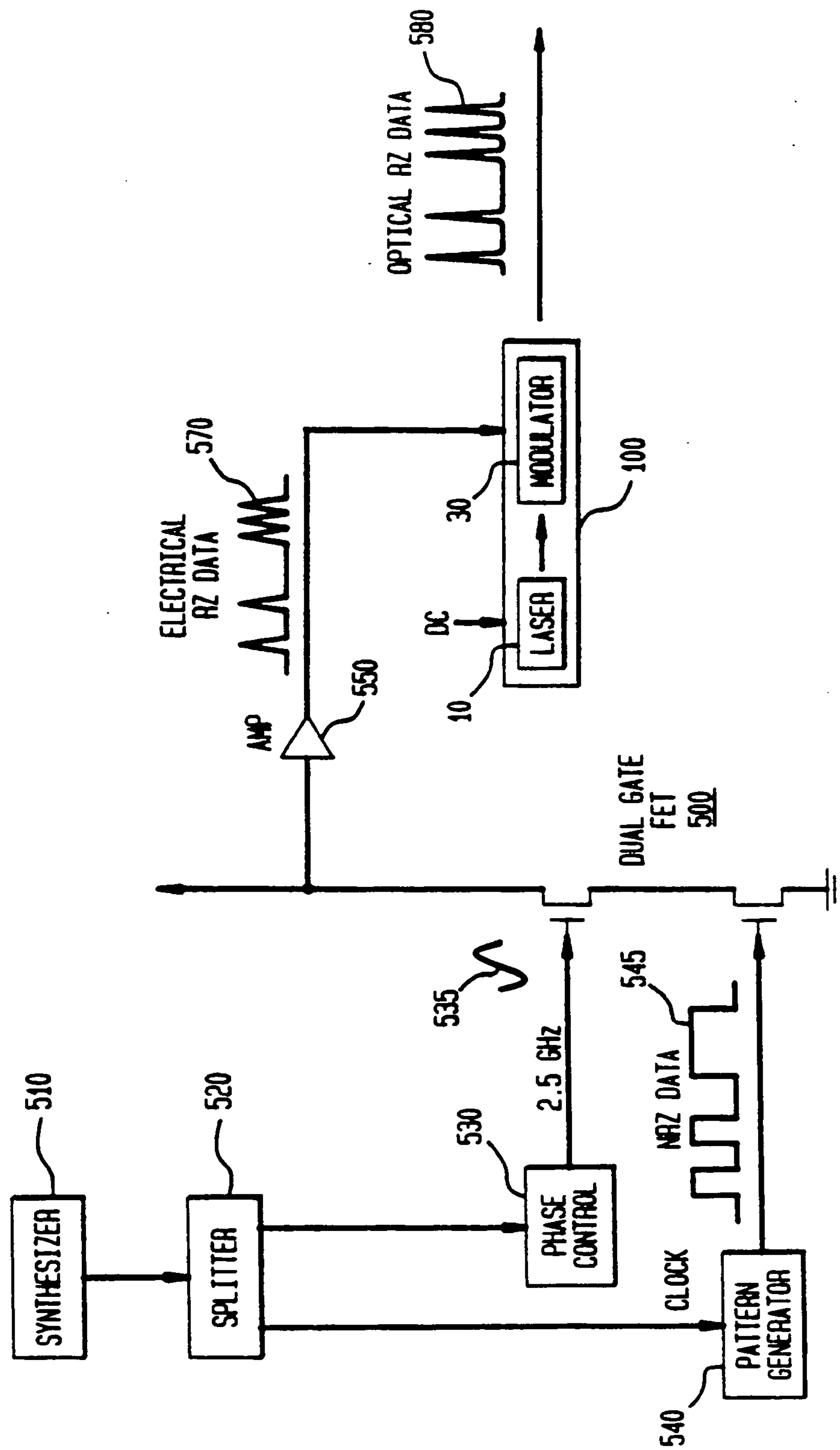

SYNTHESIZER
510
SPLITTER
520
PHASE CONTROL
530
2.5 GHz
535
CLOCK
PATTERN GENERATOR
540
NRZ DATA
545
DUAL GATE FET
500
AMP
550
ELECTRICAL RZ DATA
570
DC
LASER
10
MODULATOR
30
100
OPTICAL RZ DATA
580

FIG. 6

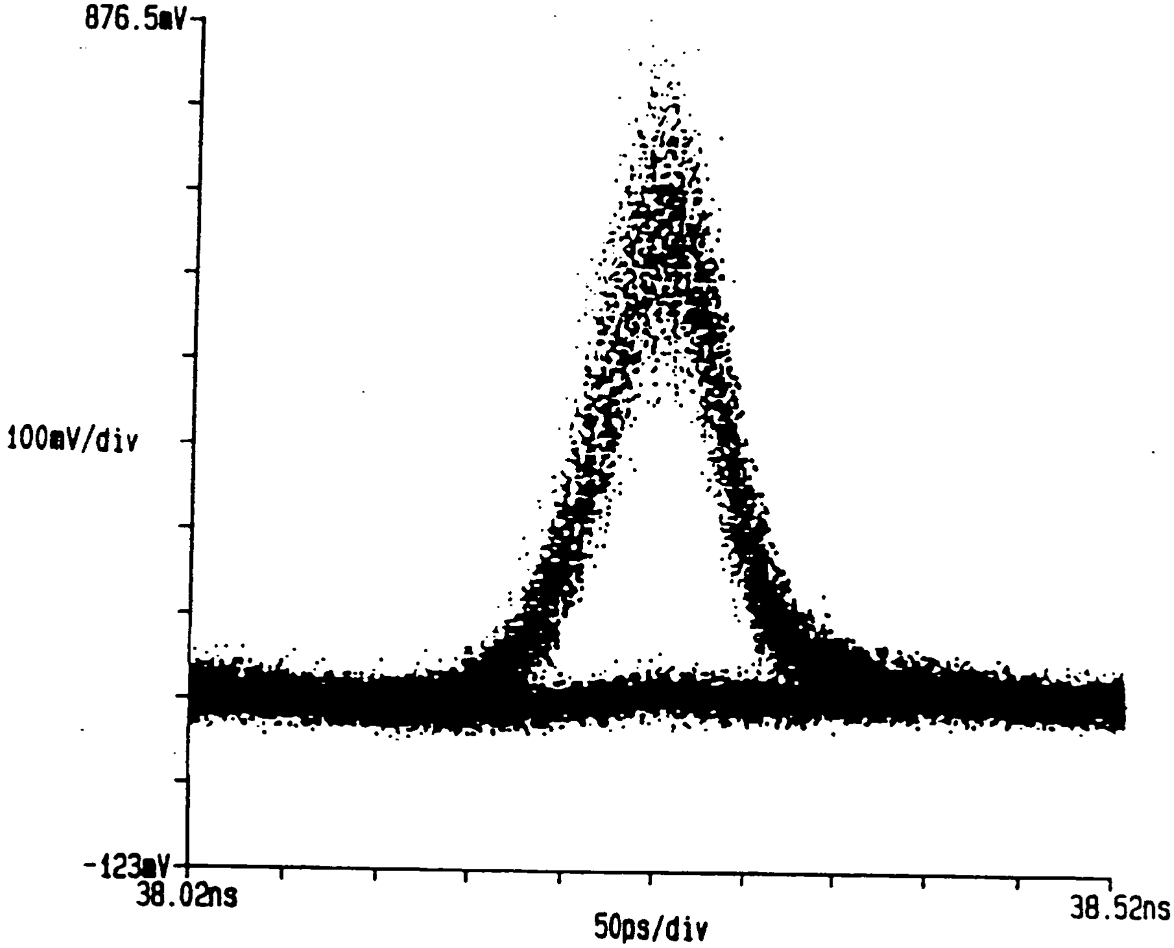


FIG. 7A

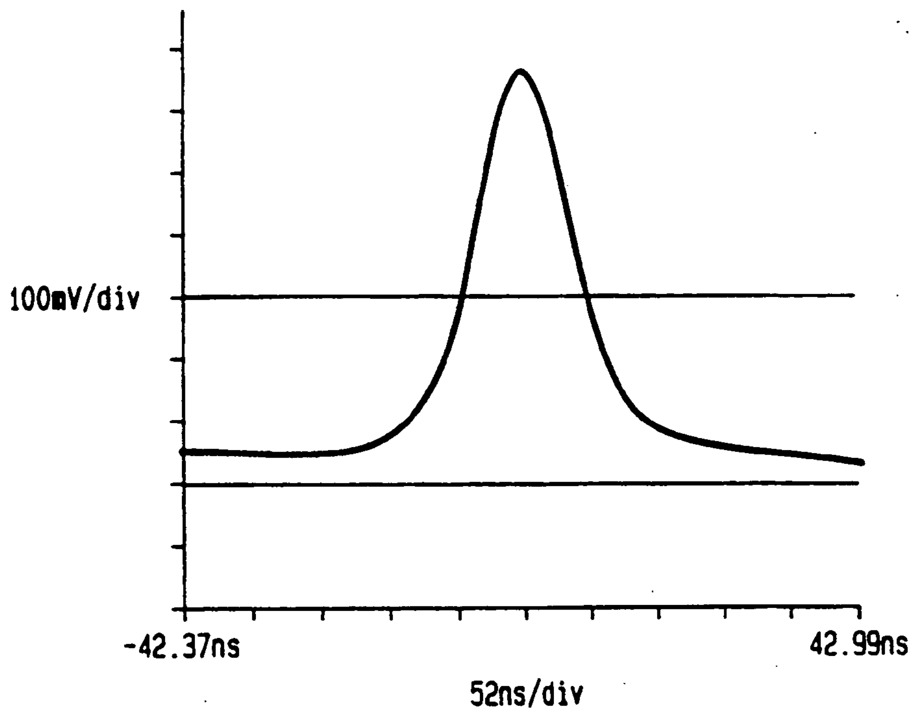


FIG. 7B

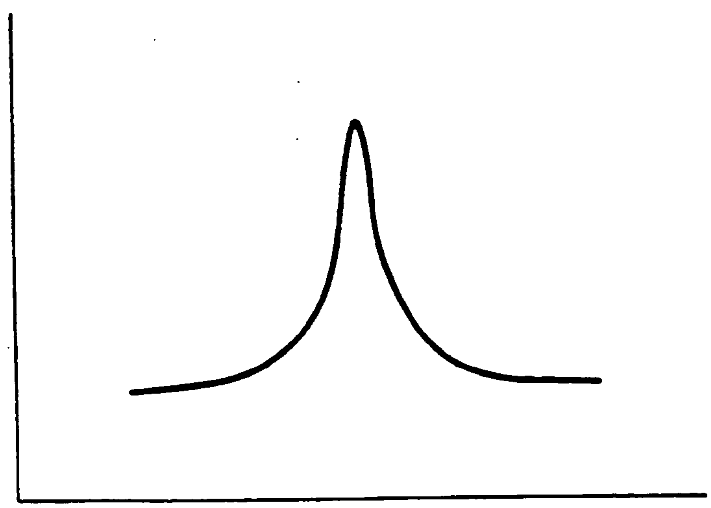
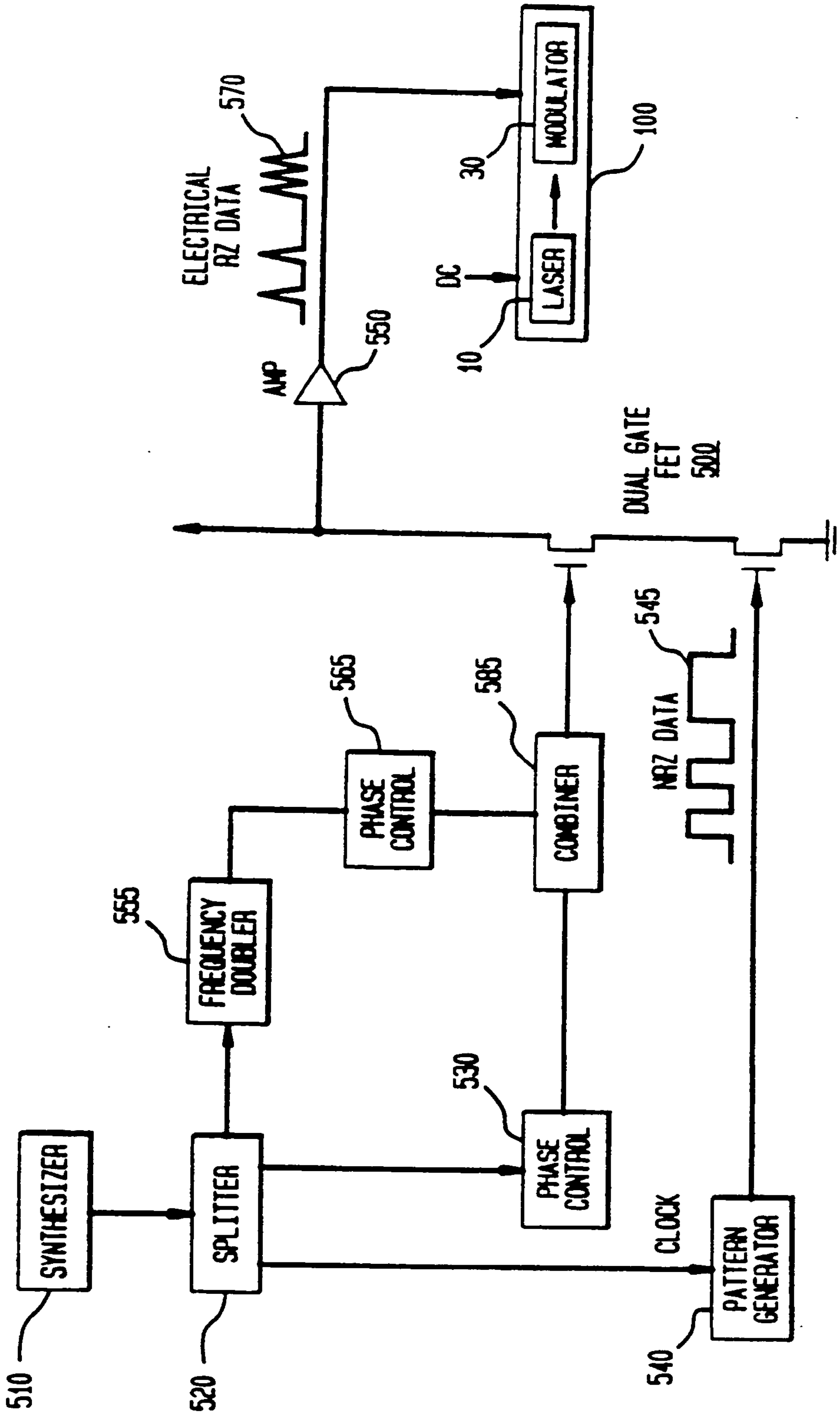


FIG. 8


SYNTHESIZER
510
SPLITTER
520
FREQUENCY DOUBLER
555
PHASE CONTROL
565
PHASE CONTROL
530
COMBINER
585
CLOCK
PATTERN GENERATOR
540
NRZ DATA
545
DUAL GATE FET
500
AMP
550
ELECTRICAL RZ DATA
570
DC
LASER
10
MODULATOR
30
100

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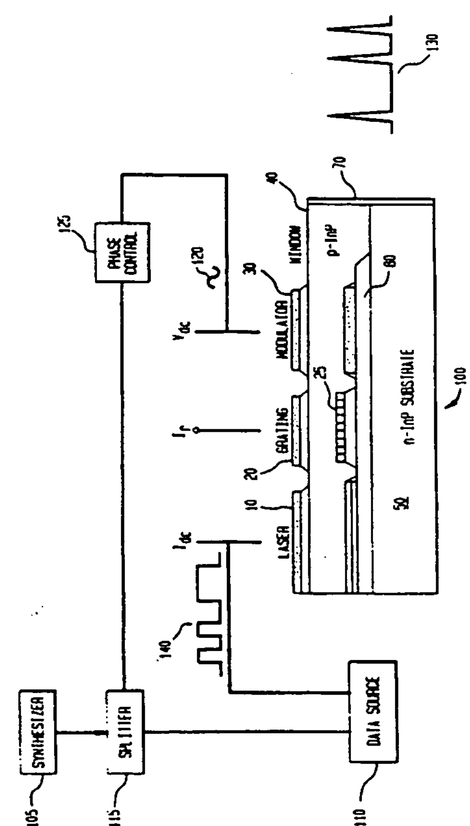

FIG. 1

EP 0 690 534 A3

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 95 30 4311

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
Y	PATENT ABSTRACTS OF JAPAN vol. 011, no. 092 (E-491) 24 March 1987 & JP-A-61 244 139 (MATSUSHITA ELECTRIC IND CO LTD) 30 October 1986 * abstract * ---	1-4	H01S3/103 H01S3/025 H04B10/145 H04B10/18 G02F1/015
Y	ELECTRONICS LETTERS, vol.29, no.18, 2 September 1993, STEVENAGE, GB pages 1643 - 1644, XP000395205 M.SUZUKI ET AL. 'Experimental investigation of Gordon-Haus limit on soliton transmission by using optical short pulses generated by an InGaAsP electroabsorption modulator' * page 1643, right column, line 5 - line 20; figure 1 * ---	1-3	
Y	ELECTRONICS LETTERS, vol.29, no.17, 19 August 1993, STEVENAGE, US pages 1528 - 1530, XP000392529 S.OSHIBA ET AL. 'Generation of transform-limited optical pulses up to 20GHz from a monolithic electroabsorption modulator/DFB laser' * the whole document * ---	1-3,7	**TECHNICAL FIELDS SEARCHED (Int.Cl.6)** H01S H04B
Y	ELECTRONICS LETTERS, vol.28, no.2, 16 January 1992, STEVENAGE, GB pages 188 - 190, XP000280613 G.RAYBON ET AL. 'Gain-switching of DBR laser monolithically integrated with electroabsorption modulator for RZ transmission' * the whole document * --- -/--	1,2,7	

~~The present search report has been drawn up for all claims~~

Place of search	Date of completion of the search	Examiner
THE HAGUE	15 January 1996	STANG, I

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

European Patent Office

CLAIMS INCURRING FEES

The present European patent application comprised at the time of filing more than ten claims.

- ☐ All claims fees have been paid within the prescribed time limit. The present European search report has been drawn up for all claims.
- ☐ Only part of the claims fees have been paid within the prescribed time limit. The present European search report has been drawn up for the first ten claims and for those claims for which claims fees have been paid.

  namely claims:
- ☐ No claims fees have been paid within the prescribed time limit. The present European search report has been drawn up for the first ten claims.

LACK OF UNITY OF INVENTION

The Search Division considers that the present European patent application does not comply with the requirement of unity of invention and relates to several inventions or groups of inventions,
namely:

see sheet B

- ☐ All further search fees have been paid within the fixed time limit. The present European search report has been drawn up for all claims.
- ☐ Only part of the further search fees have been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the inventions in respect of which search fees have been paid.

  namely claims:
- ☒ None of the further search fees has been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the invention first mentioned in the claims.

  namely claims: 1-7

European Patent Office

EUROPEAN SEARCH REPORT

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DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
Y	ELECTRONICS LETTERS, vol.30, no.8, 14 April 1994, STEVENAGE, GB pages 650 - 651, XP000451515 N.M.FROBERG ET AL. 'Pulse generation by harmonic modulation of an integrated DBR laser-modulator' * the whole document * ---	1,2,4,7	
A	IEEE PHOTONICS TECHNOLOGY LETTERS, vol.5, no.9, 3, NEW YORK, US pages 1098 - 1100, XP000414187 K.C.REICHMANN ET AL. '2.5Gb/s Transmission over 674km at multiple wavelengths using a tunable DBR laser with an integrated electroabsorption modulator' * paragraph II; figure 1 * -----	5-7	
			TECHNICAL FIELDS SEARCHED (Int.Cl.6)

~~The present search report has been drawn up for all claims~~

Place of search	Date of completion of the search	Examiner
THE HAGUE	15 January 1996	STANG, I

CATEGORY OF CITED DOCUMENTS

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EPO FORM 1503 03.82 (P04C01)

European Patent Office

EP 95 30 4311 -B-

LACK OF UNITY OF INVENTION

The Search Division considers that the present European patent application does not comply with the requirement of unity of invention and relates to several inventions or groups of inventions, namely:

1. Claims 1-7 :

   Apparatus used for RZ-encoding of optical pulses in which the electrical data pulses are applied to a semiconductor laser and a periodic analog signal is applied to a modulator.

2. Claims 8-10 :

   The same apparatus as above in which the semiconductor laser generates a continuous output and RZ electrical data pulses are applied to the modulator.

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